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RELATION OF HEAT TREATMENT TO THE MICROSTRUCTURE OF 60-40 BRASS

by

Robert S. Williams and Victor O. Homerberg.

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TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS [SUBJECT TO REVISION]

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DISCUSSION OF THIS PAPER IS INVITED. It should preferably be presented in person at the New York Meeting, February, 1924, when an abstract of the paper will be read. If this is impossible, discussion in writing may be sent to the Editor, American Institute of Mining and Metallurgical Engineers, 29 West 39th Street, New York, N. Y., for presentation by the Secretary or other representative of its author. Unless special arrangement is made, the discussion of this paper will close April 1, 1924. Any discussion offered thereafter should preferably be in the form of a new paper.

Relation of Heat Treatment to the Microstructure of 60–40 Brass

By Robert S. Williams,* Ph.D., Victor O. Homerberg,† P.D.,
Cambridge, Mass.

(New York Meeting, February, 1924)

A description is given of a double heat treatment of 60–40 *brass. Photomicrographs are included to show the changes that take place in the microstructure on reheating the water-quenched specimens. A wide variation in the mechanical properties may be obtained by the described heat-treatment method.*

On several occasions, when 60–40 brass is first obtained in the beta condition by quenching at about 825° C. and is then reheated, the writers have noticed that recrystallization will take place in the form of twin crystals at the grain boundaries of the original beta crystals. It was, therefore, thought that interesting results would be obtained if this twinning process was studied further, especially as to the temperature at which it first occurs. The material used in the investigation was a bar of extruded muntz metal, ½ in. in diameter, and of the following composition: Copper, 60.21 per cent.; zinc, 39.73 per cent.; lead, trace; iron, trace; tin, *nil.*

Specimens 1 in. in length were sawed from this bar and a hole was drilled into the side of each specimen until it reached the center, and the tip of a platinum-platinum rhodium thermocouple was inserted. A small Hoskins' resistance-type electric furnace was used for heating the specimens.

The specimens were first heated at 840° C. for 2 hr. and then quenched in cold water, in order to get the material entirely in the beta state. In every case, in the reheating process, the furnace was brought to the desired temperature before the specimen was introduced. The time occupied in preheating was from 20 to 30 min. By sawing back ¼ in. on each side of the hole, two parts were obtained from each specimen

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and duplicate observations were possible. The specimens were held at the reheating temperatures for periods of 15 min., 30 min., 1, 2, and 4 hr. All specimens were etched with a freshly prepared mixture of equal volumes of concentrated NH_4OH and H_2O_2.

A reheating of the quenched specimen resulted in a breakdown of the beta into finely divided alpha. Figs. 1 and 2 show this condition in the specimens reheated at 440° C. for ½ hr. and 1 hr. respectively. No indication of the production of alpha twins was apparent in these specimens.

Carpenter[1] has shown that there is a thermal change at about 470° C., as first determined by Roberts-Austen[2] but attributed to experimental defects in the apparatus by Shepherd,[3] Tafel,[4] and Bornemann.[5] Carpenter detected this critical point pyrometrically by both heating and cooling curves in all alloys of copper and zinc ranging from 63 to 40 per cent. copper. He concluded that at 470° C., on cooling, beta splits up into alpha and gamma.

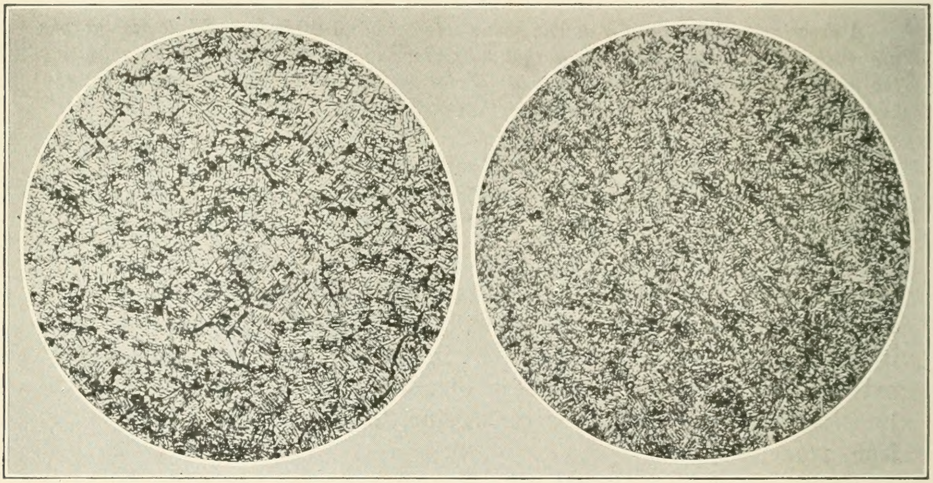

Fig. 1.—Specimen rehfated at 440° C. for 30 min. × 100.

Fig. 2.—Specimen reheated at 440° C. for 1 hr. × 100.

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[1] H. C. H. Carpenter and C. A. Edwards: "A New Critical Point in Copper Zinc Alloys." *Jnl.* Inst. of Metals (1911) **5,** 127–149.

[2] Roberts-Austen: Fourth Report to the Alloys Research Committee of the Institution of Mechanical Engineers (1897) 31–100.

[3] E. S. Shepherd: "The Constitution of the Copper-zinc Alloys." *Jnl. Phys. Chem.* (1904) **8,** 421.

[4] V. E. Tafel: *Metallurgie* (1908) **5,** 378.

[5] K. Bornemann: *Metallurgie* (1909) **6,** 247.

Stead and Stedman[6] subjected specimens of cast and cold-rolled muntz metal to prolonged heating of 3 months at 430° C. and for 984 hr. at 270° C., but failed to detect any clear evidence of segregated gamma and, therefore, held the tentative view that the disappearance of the beta constituent was due entirely to solution in the alpha.

The critical point was again considered by Hudson,[7] who contended that the heat effect must be due to a polymorphic transformation of the beta constituent from beta to beta prime, and advanced evidence to support his belief. Hudson gave evidence of the formation of beta prime by annealing alpha + gamma at temperatures below the critical point.

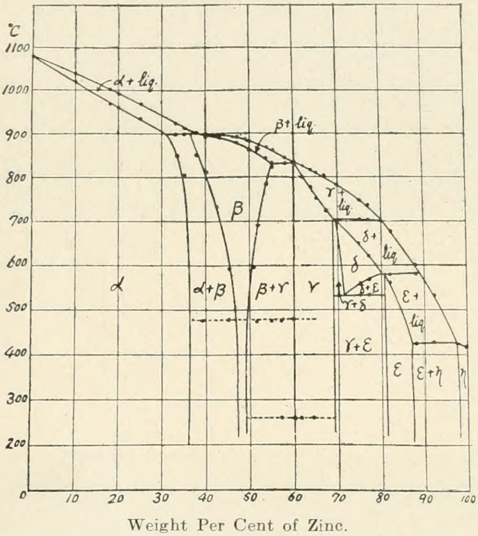

FIG. 3.—EQUILIBRIUM DIAGRAM OF COPPER-ZINC SYSTEM.

Recently an equilibrium diagram of the copper-zinc system has been obtained by Imai,[8] chiefly by means of electric-resistance measurements. This diagram, Fig. 3, nearly coincides with those of Shepherd and Tafel. As to the transformation of the beta constituent, Imai obtained a negative result for a eutectoid separation or an allotropic change.

A significant result of the present investigation is that recrystallization is shown to begin at about 460° C. The first indication of recrystallization, in the form of twinning at the grain boundaries of the original

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[6] J. E. Stead and H. G. A. Stedman: "Muntz Metal." *Jnl.* Inst. of Metals (1914) **11,** 119–134.

[7] O. F. Hudson: "The Critical Point at 460° C. in Zinc-copper Alloys." *Jnl.* Inst. of Metals (1914) **12,** 89–101.

[8] Imai: "Equilibrium of the Copper-zinc System." *Sci. Repts.* Tohoku Imperial Univ., **11,** 313–332.

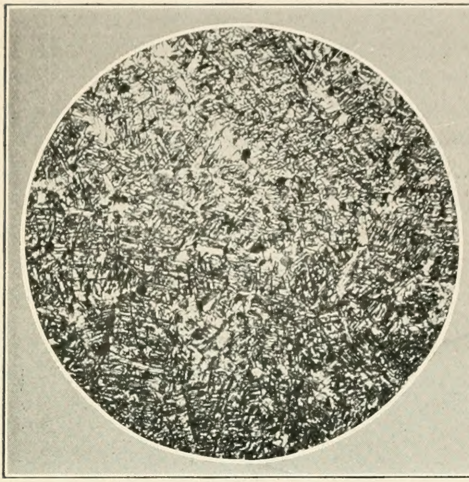

Fig. 4.—Specimen reheated at 465° C. for 2 hr. × 100.

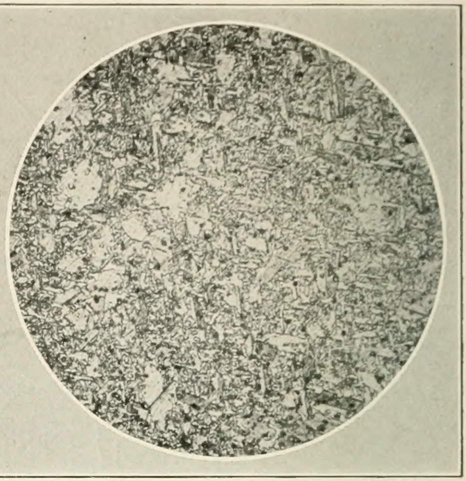

Fig. 5.—Specimen reheated at 465° C. for 80 hr. × 100.

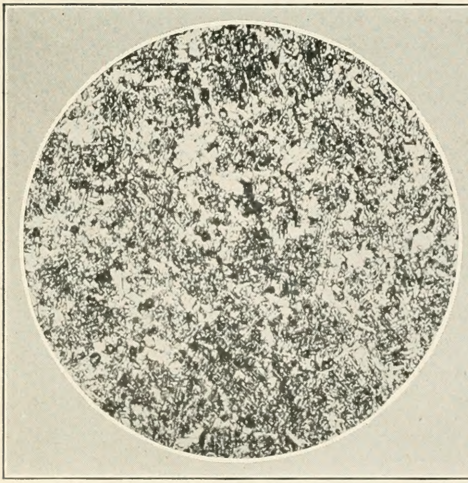

Fig. 6.—Specimen reheated at 495 °C. for 15 min. × 100.

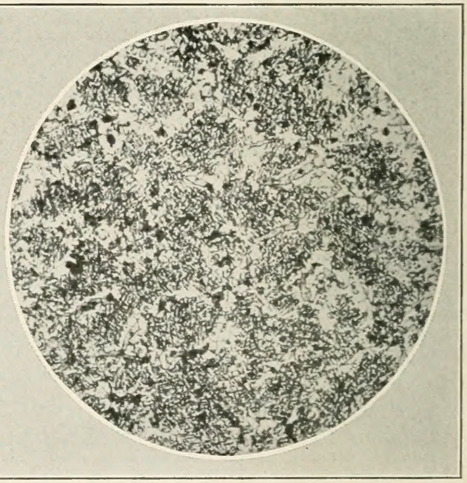

Fig. 7.—Specimen reheated at 495° C. for 30 min. × 100.

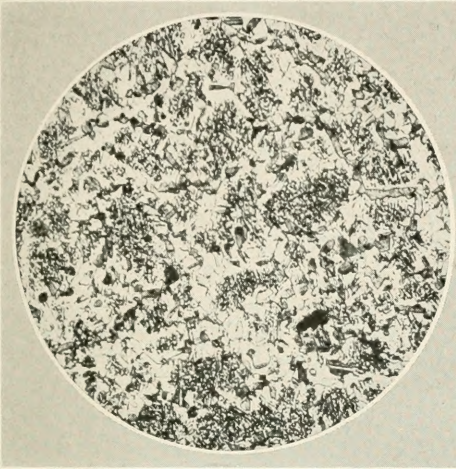

FIG. 8.—SPECIMEN REHEATED AT 495° C. FOR 1 HR. × 100.

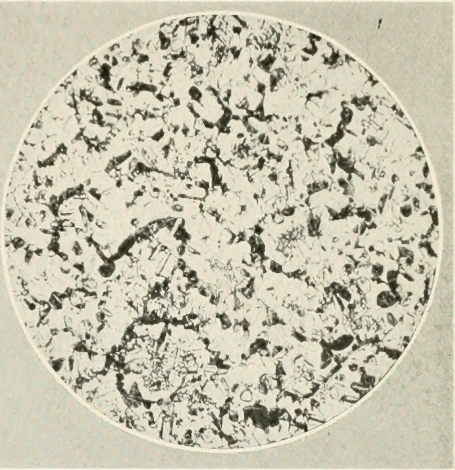

FIG. 9.—SPECIMEN REHEATED AT 500° C. FOR 2 HR. × 100.

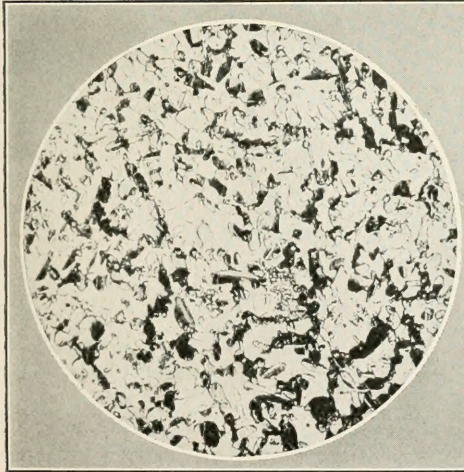

FIG. 10.—SPECIMEN REHEATED AT 500° C. FOR 4 HR. × 100.

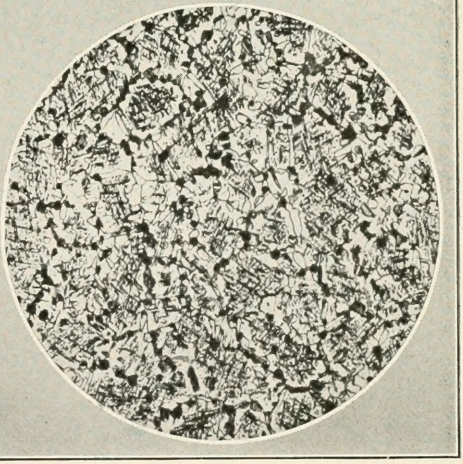

FIG. 11.—SPECIMEN REHEATED AT 530° C. FOR 15 MIN. × 100.

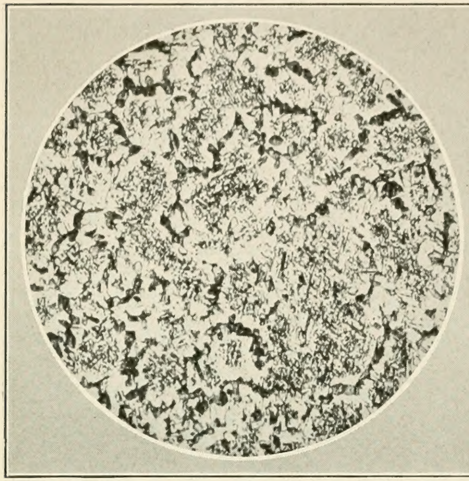

Fig. 12.—Specimen reheated at 530° C. for 30 min. × 100.

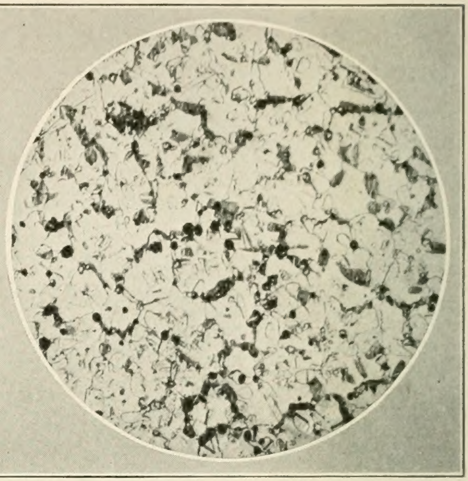

Fig. 13.—Specimen reheated at 530° C. for 1 hr. × 100.

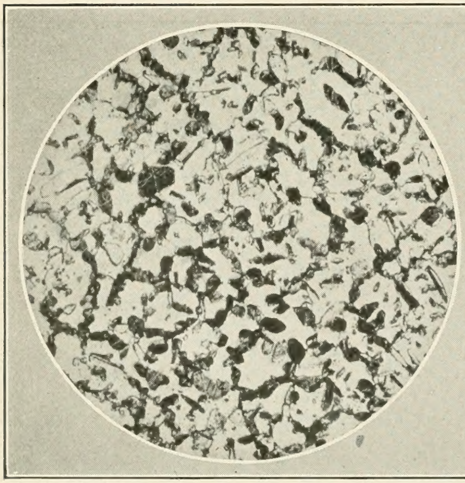

Fig. 14.—Specimen reheated at 530° C. for 2 hr. × 100.

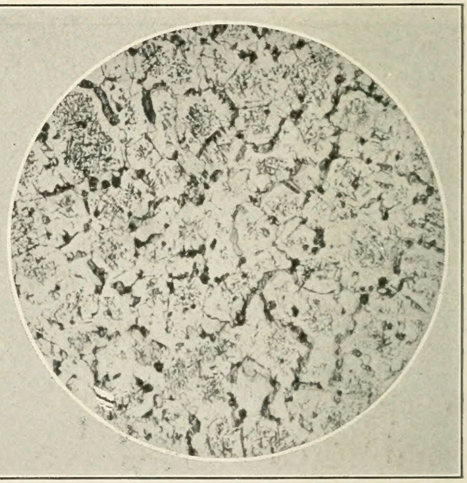

Fig. 15.—Specimen reheated at 575° C. for 15 min. × 100.

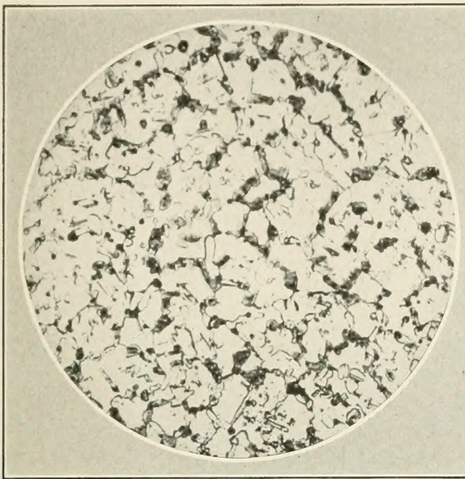

Fig. 16.—Specimen reheated at 575° C. for 30 min. × 100.

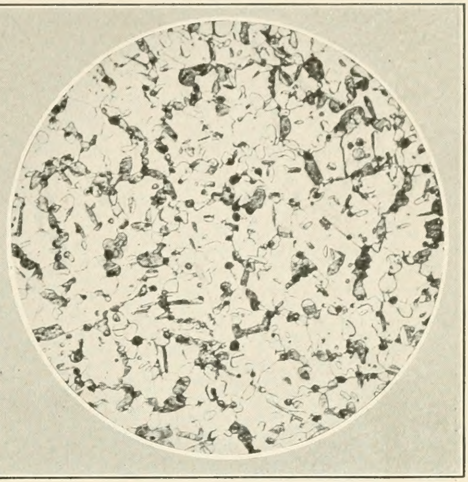

Fig. 17.—Specimen reheated at 575° C. for 1 hr. × 100.

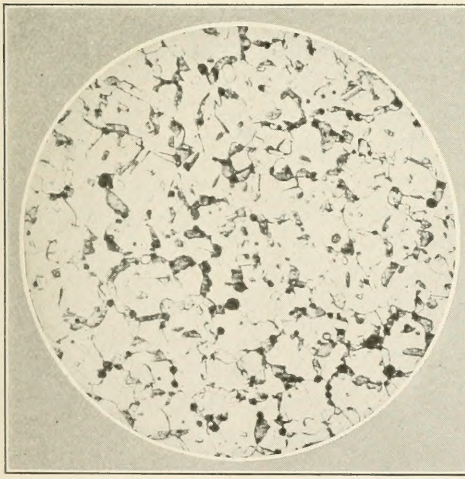

Fig. 18.—Specimen reheated at 575° C. for 2 hr. × 100.

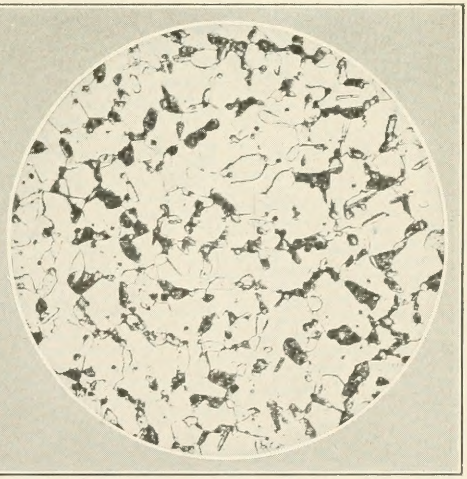

Fig. 19.—Specimen reheated at 575° C. for 4 hr. × 100.

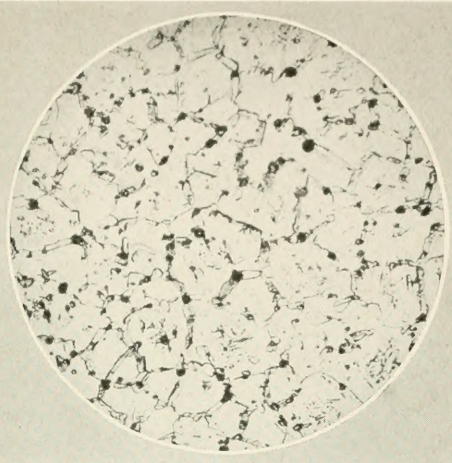

FIG. 20.—SPECIMEN REHEATED AT 605° C. FOR 15 MIN. × 100.

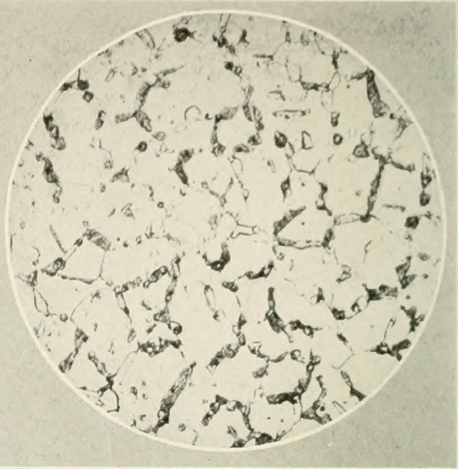

FIG. 21.—SPECIMEN REHEATED AT 605° C. FOR 45 MIN. × 100.

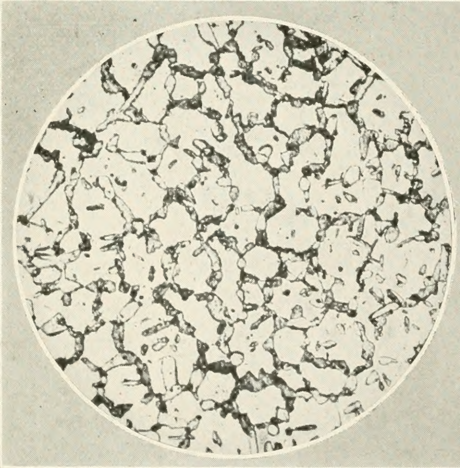

FIG. 22.—SPECIMEN REHEATED AT 605° C. FOR 1 HR. × 100.

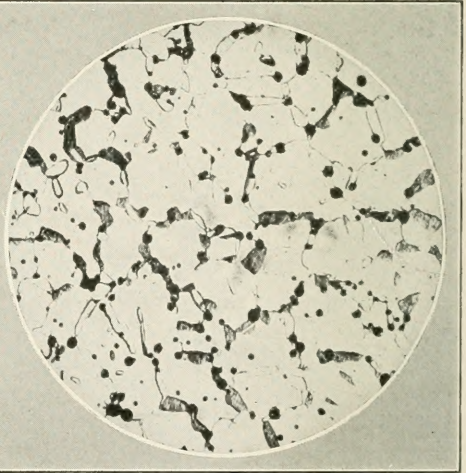

FIG. 23.—SPECIMEN REHEATED AT 605° C. FOR 2 HR. × 100.

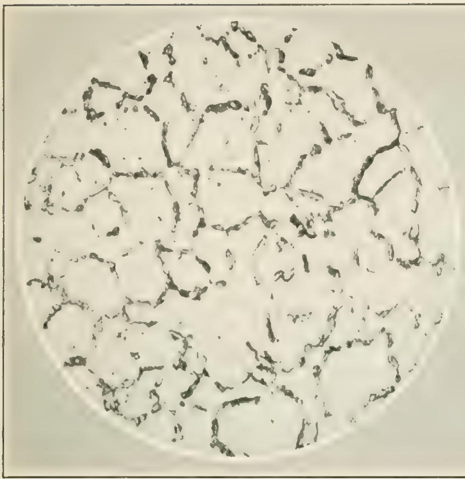

Fig. 24.—Specimen reheated at 660° C. for 15 min. × 100.

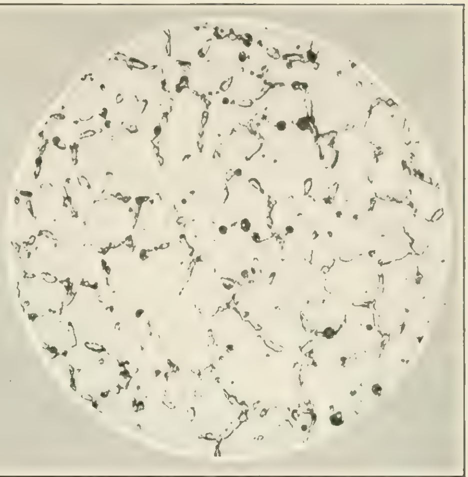

Fig. 25.—Specimen reheated at 660° C. for 30 min. × 100.

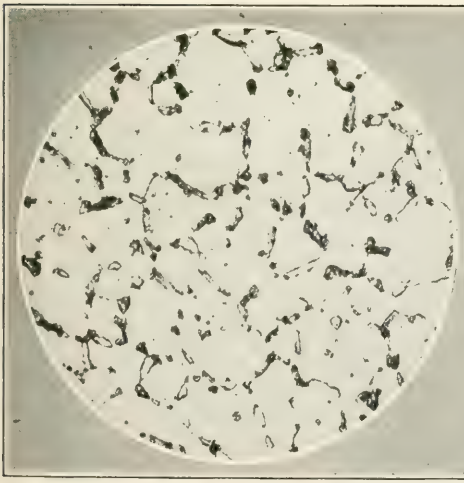

Fig. 26.—Specimen reheated at 660° C. for 1 hr. × 100.

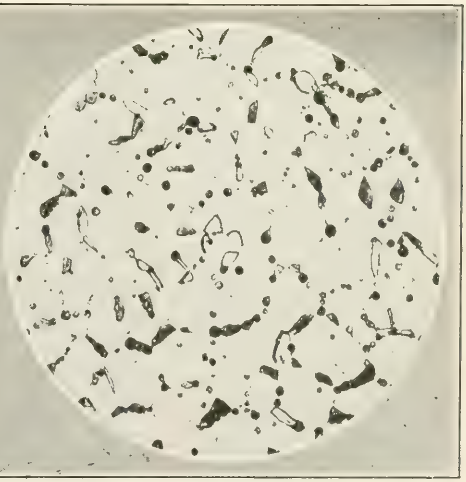

Fig. 27.—Specimen reheated at 660° C. for 2 hr. × 100.

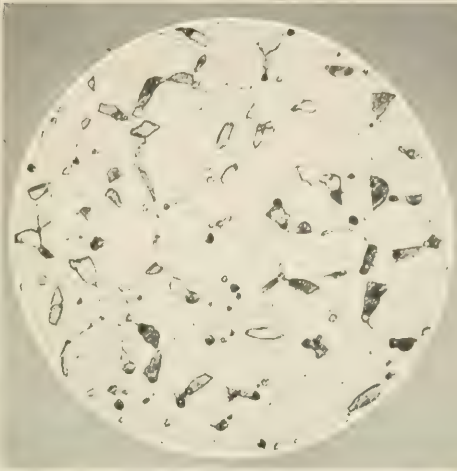

FIG. 28.—SPECIMEN REHEATED AT 660° C. FOR 4 HR. × 100.

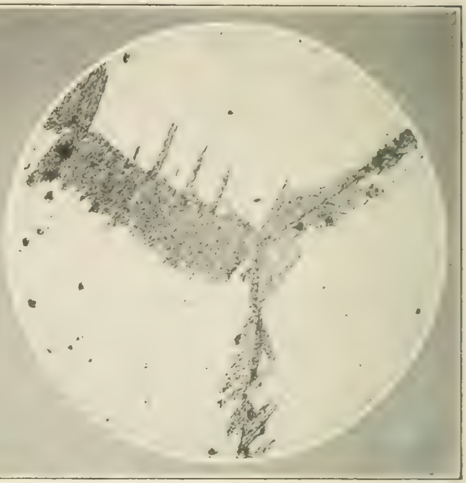

FIG. 29.—SPECIMEN REHEATED AT 150° C. FOR 2 HR. × 250.

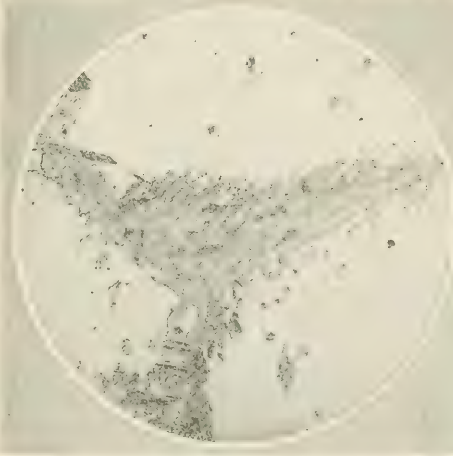

FIG. 30.—SPECIMEN REHEATED AT 200° C. AND QUENCHED IN WATER. × 250.

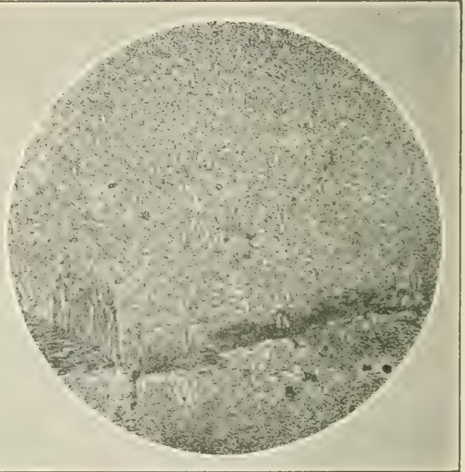

FIG. 31.—SPECIMEN REHEATED AT 200° C. FOR 1 HR. × 250.

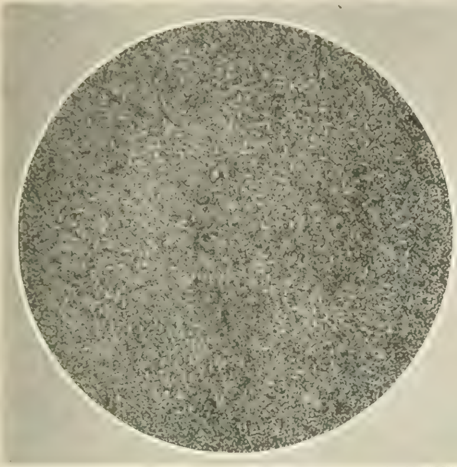

Fig. 32.—Specimen reheated at 200° C. for 2 hr. × 250.

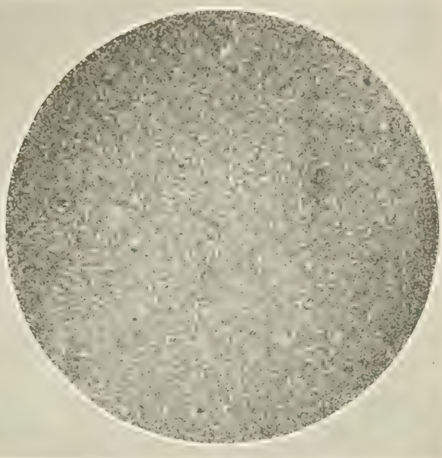

Fig. 33.—Specimen reheated at 300° C. for 3 hr. × 250.

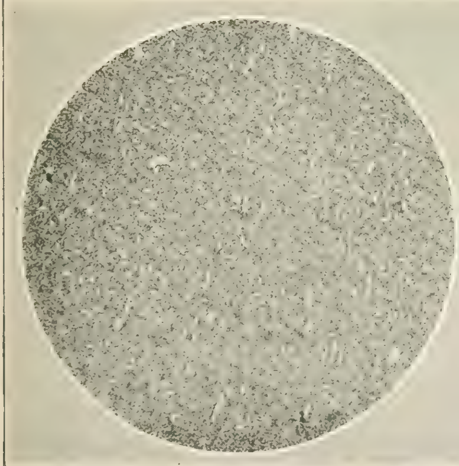

Fig. 34.—Specimen reheated at 400° C. for 2 hr. × 250.

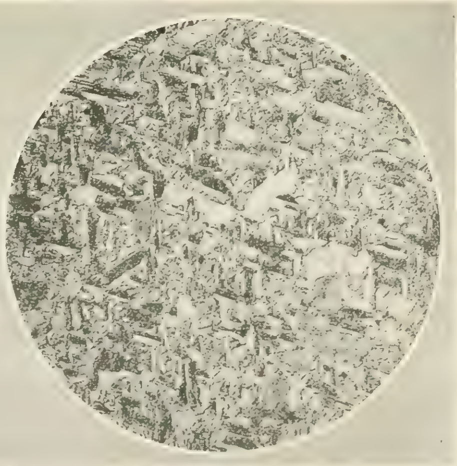

Fig. 35.—Specimen reheated at 460° C. for 2 hr. × 250.

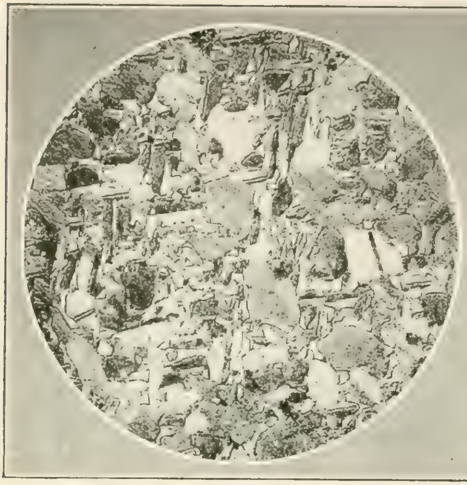

Fig. 36.—Specimen reheated at 500° C. for 2 hr. × 250.

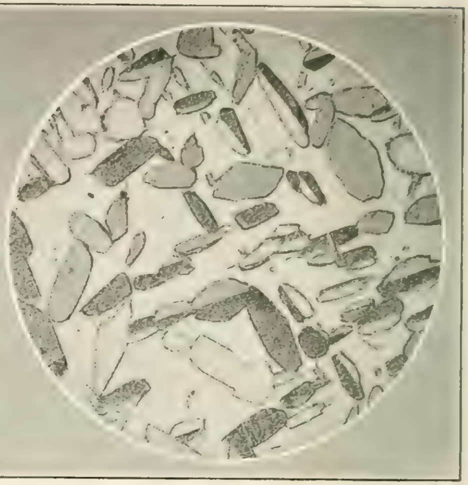

Fig. 37.—Specimen reheated at 600° C. for 2 hr. × 250.

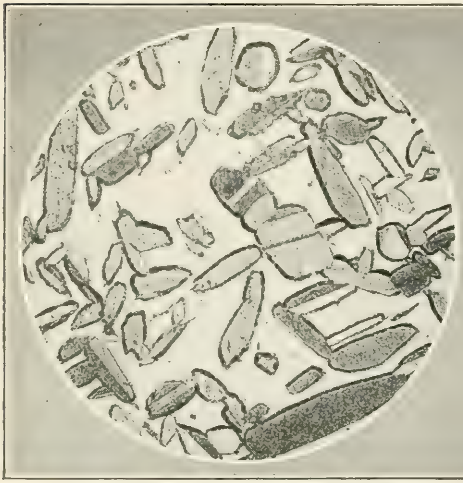

Fig. 38.—Specimen reheated at 700° C. for 2 hr. × 250.

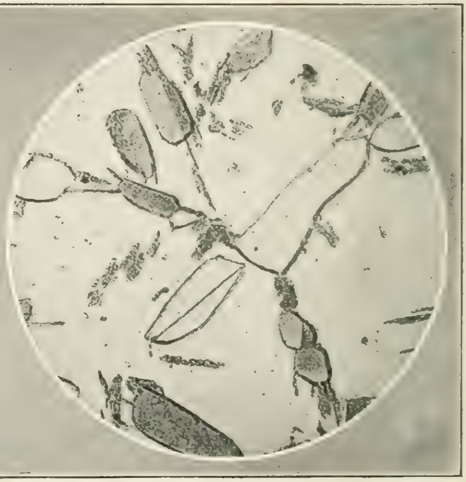

Fig. 39.—Specimen reheated at 750° C. for 2 hr. × 250.

beta crystals, is shown in Fig. 4; this specimen was reheated at 465° C. for 2 hr. In Fig. 5 is shown a specimen reheated at 455° C. for 80 hr.; this shows a number of alpha twins together with considerable needlelike alpha. The present writers were unable to obtain the gamma constituent in 60–40 brass.

The presence of alpha twins at the grain boundaries of the original beta grains becomes more marked as the temperature and the time of reheating are increased; the various stages are shown in Figs. 6 to 28. The appearance of the fine boundaries of the beta grains and unabsorbed alpha is shown in Figs. 27 and 28. All specimens were quenched in water from the reheating temperature.

To corroborate the results obtained with bar No. 1, another rod was selected, sawed into specimens, and prepared in the same manner. The composition of the bar was: Copper, 61.05 per cent.; zinc (by difference), 38.90 per cent.; lead, 0.05 per cent.; iron, trace; tin, *nil*.

All of the specimens were heated at 825° C. for 2 hr. and quenched in cold brine and then reheated at the following temperatures: 150, 200, 300, 400, 460, 500, 600, 700, and 750° C. One set was quenched as soon as the reheating temperature was reached. Other specimens were held at the respective temperatures for periods of 1/2, 1, 2, and 4 hr. and then quenched in water. Figs. 29 to 39, show the structures obtained.

Again, there resulted a breakdown of the beta into a very fine alpha, which closely resembles martensite as shown in Fig. 34. Finely divided alpha was obtained after reheating at 200° C. for 1 hr. The beta grains with fringes of alpha at the grain boundaries are shown in Figs. 29 and 30. In almost every case, with the exception of the specimens prepared from bar No. 1, an alpha fringe was obtained after quenching in an attempt to obtain beta alone. This alpha fringe seldom, if ever, forms twin crystals on annealing but gradually goes into solution as the reheating temperature is increased. This fact is rather remarkable inasmuch as the alpha resulting from the breakdown of the beta forms twin crystals of alpha at about 460° C. as shown in Fig. 35.

If extruded material is annealed, the alpha masses will ultimately form twin crystals. If this extruded material is heated into the beta range, cooled in the furnace, and then reheated, the resultant alpha masses will not form twin crystals but will gradually go into solution to form beta as the reheating temperature is increased. If the material containing the alpha fringes at the grain boundaries is compressed, the fringed alpha will form twin crystals on annealing, as would be expected from the well-known fact that mechanical work and annealing are both necessary for the production of twinned alpha. The fact that twinned alpha results from the annealing of quenched beta must imply that the operation of quenching is, in this case, equivalent to working. In this connection, attention is again called to the fact that the fringe of alpha does not form these twin crystals. The alpha must be worked before it will form twin crystals on annealing; this phenomenon is well known. It seems strange, therefore, that the alpha resulting from the breakdown of the beta, on reheating, should form twin crystals and that the fringe of alpha does not form these twin crystals.

Another interesting fact was observed when working with bar No. 1. In the discussion of Carpenter's paper, it was stated that muntz metal should be heated at 850° C. for 5 hr. and then quenched under very definite conditions in order to obtain beta free from alpha. Specimens from bar No. 1 were heated at 830° C. for periods varying from 15 min. to 4 hr. and quenched in cold brine. The specimen that was quenched after 15 min. heating showed no alpha. All of the specimens were practically free from alpha at the grain boundaries; this result would indicate that the rate of cooling is the important factor to consider and that 5 hr. heating, as suggested by Carpenter, is unnecessary.

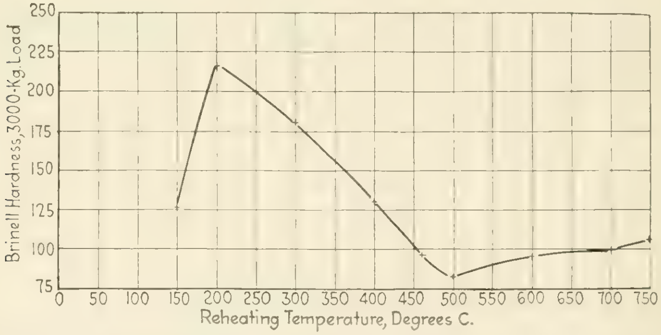

Fig. 40.—Brinell hardness at various reheating temperatures.

Fig. 36 shows the structure to be almost entirely twinned alpha. As the temperature is increased the proportion of beta also increases. Fig. 39 shows the presence of both twinned alpha, which represents alpha that has not been absorbed, and granular alpha, which is the alpha that comes out of the beta on quenching.

It is obvious that a range of mechanical properties might be anticipated from the various structures obtained on reheating. Brinell hardness values were determined on the specimens from rod No. 2. The accompanying table and Fig. 40 show interesting results for Brinell hardness under a 3000-kg. load. It will be noted that the maximum hardness is obtained at a reheating temperature of 200° C.; and as the structure becomes coarsened, the hardness values drop, reaching a minimum between 460 and 500° C. This minimum value is at the point at which the structure is practically all twinned alpha; the hardness increases slowly as the proportion of beta increases. The time of reheating for the specimens that were tested was 2 hours.

Reheating Temperature, Degrees C.	Brinell Hardness (3000 Kg.)	Reheating Temperature, Degrees C.	Brinell Hardness (3000 Kg.)	Reheating Temperature, Degrees C.	Brinell Hardness (3000 Kg.)
150	126	400	131.0	600	90.3
200	217	460	92.0	700	99.2
300	179	500	87.1	750	111.0

Conclusions

Specimens of 60–40 brass, when quenched to form beta, break down into finely divided alpha at approximately 200° C. This alpha gets coarser as the reheating temperature is increased and forms twinned alpha at 450–460° C. At this temperature the material consists almost entirely of alpha twins. The twin crystals form first at the grain boundaries of the original beta grains, provided there is no alpha fringe at these boundaries. As the reheating temperature is increased, beta becomes more prominent because of the absorption of the alpha.

The alpha fringe is gradually absorbed without the formation of twin crystals as the reheating temperature is increased. This fringe will form twin crystals if it is subjected to cold work before it is annealed.

The alpha masses in extruded 60–40 brass form twin crystals on annealing, but such is not the case with material heated at 825° C., cooled slowly in the furnace, and then annealed.

The Brinell hardness is a maximum at the point where the alpha resulting from the breakdown of the beta is in the most finely subdivided state. It is a minimum at the temperature at which the material consists of twinned alpha; it increases again as the quantity of beta increases.

A wide range of mechanical properties is predicted for 60–40 brass when subjected to a double heat treatment.